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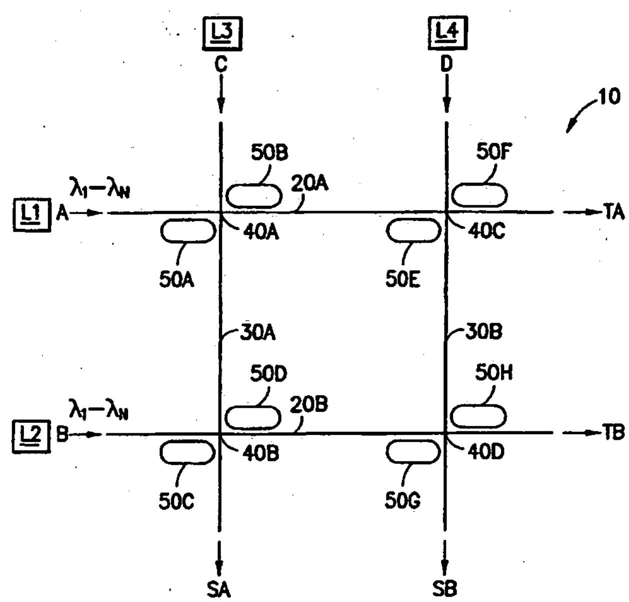
(54) Title: M x N OPTICAL CROSS-CONNECT



(57) Abstract: An optical cross-connect is provided which includes an M quantity of first waveguides and an N quantity of second waveguides. The second waveguides intersecting the first waveguides with a node being defined at each intersection. At least one switching element (preferably an oval resonator) is disposed adjacent to each of the nodes to selectively transfer portions of the signals between the waveguides. To minimize cross-talk between the signals, the waveguides are enlarged at, and in proximity to, the nodes to reduce diffraction of the signals.

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— *Before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments.*

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M x N OPTICAL CROSS-CONNECT

FIELD OF THE INVENTION

This invention relates to nanophotonic devices, and, more particularly, to optical cross-connect devices.

BACKGROUND OF INVENTION

Optical switches (i.e., crossbars, cross-connects, etc.) may be used to solve the problem of switching, routing, interconnecting, etc. the various wavelengths of an optical signal propagating in an optical network. The number of wavelengths provided in a single optical signal has increased, and continues to increase dramatically with the widespread use of dense wave division multiplexing communication systems, networks, and methodologies.

Cross-connects are known in the prior art. Moreover, the use of cross-connects in fiber optic applications, such as wave division multiplexing (WDM) and dense wave division multiplexing (DWDM) is known. However, improvements in optical cross-connects are always desirable to minimize cross-talk between adjoining signals, as well as, to minimize signal losses in switching. Cross-talk is the undesired coupling of a signal into an unintended path.

Thus, there exists a need in the art for an optical device that overcomes the above-described shortcomings of the prior art.

SUMMARY OF THE INVENTION

The aforementioned object is met by an optical cross-connect which includes a M quantity of first waveguides and a N quantity of second waveguides, with the second waveguides intersecting the first waveguides. Each intersection of a first waveguide and a second waveguide defines a node with, preferably, a plurality of optical switching elements being located in

proximity thereto. The switching elements are, preferably, optical devices which selectively control signal transfer between the waveguides defining the node without having to convert the light signals into electrical signals to do so. Preferably, the switching elements are resonators, and, more preferably oval resonators. The switching elements may also be in the form of directional couplers where frequency selectivity is not critical, or, alternatively, MEMS (micro-electromechanical system) switches with mirrors.

By utilizing the subject invention, the first and second waveguides each carry light signals comprising one or more wavelengths. By manipulating the switch elements, all or portions of the light signals may be switched from waveguide to waveguide. For example, in the preferred embodiment, the resonators are tuned so as to couple portions of the signals of a particular wavelength. Tuning is achieved through the controlled application of electrical voltages to the resonators using techniques known to those skilled in the art. Likewise, the directional couplers may be controlled. With directional couplers, however, there is a deactivated state in which all, or substantially all, of a light signal is coupled, or an activated state in which all, or substantially all, of a light signal by-passes the directional coupler without coupling. The application of an electric voltage causes activation of the directional coupler.

In a further aspect of the subject invention, the nodes are increased in area so as to reduce cross-talk between signals, as well as reduce signal losses. Specifically, the waveguides are enlarged about and at the node. With the enlarged area, diffraction of signals is reduced, thereby reducing loss, and the signals are able to pass through the node with less cross-talk.

The subject invention advantageously provides for signal switching between a plurality of waveguides with minimal loss, and is utilizable in multiplexing and demultipexing systems (WDM and DWDM). Furthermore, the device can be formed as a semiconductor package which can be assembled with other semiconductor devices in forming a device and/or system.

The invention accordingly comprises the features of construction, combination of elements, and arrangement of parts which will be exemplified in the disclosure herein, and the scope of the invention will be indicated in the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawing figures, which are not to scale, and which are merely illustrative, and wherein like reference numerals depict like elements throughout the several views:

FIG. 1 is a top plan view of an optical cross-connect having one first waveguide and one second waveguide;

FIG. 2 is a partial cross-sectional view of the optical cross-connect of FIG. 1 taken along line 2-2 of FIG 1;

FIG. 3 is a top plan view of an optical cross-connect having two switching elements;

FIG.4 is a top plan view of an optical cross-connect having two first waveguides and two second waveguides;

FIG. 5 is a top plan view of an optical cross-connect having four switching elements being disposed in proximity to a single node;

FIG. 6 is a top plan view of an elliptical resonator;

FIG. 7 is a top plan view of a circular resonator;

FIG. 8 is a top plan view of an optical cross-connect utilizing a directional coupler as a switching element;

FIGS. 9A and 9B show two different embodiments of a node having an enlarged area; and,

FIG. 10 is a top plan view of an optical cross-connect with first and second waveguides having portions which are generally parallel.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, an optical cross-connect is shown and generally depicted with the reference numeral 10. The optical cross-connect 10 is formed of a M quantity of first waveguides 20 and a N quantity of second waveguides 30. The second waveguides 30 intersect the first waveguides 20 with a node 40 being defined at each intersection of waveguides 20, 30. Additionally, the optical cross-connect 10 includes at least one optical switching element 50 associated with each of the nodes 40, with the switching element 50 being located in proximity to the associated node 40. In the preferred embodiment, the switching element 50 is an optical device which can couple light signals (entirely or wavelength portions thereof) without converting the signals to electrical signals. Preferably, the switching element 50 is an oval resonator having two arcuate ends 51 and two straight portions 52 extending therebetween which are generally parallel. Copending application Serial No. ___________, to the same inventors and assignee as herein, describes in detail an oval resonator utilizable with the subject invention, and said disclosure is incorporated by reference.

The optical cross-connect 10 may be formed with any of the quantities M and N of the first and second waveguides 20, 30, respectively. By way of non-limiting example, reference is made to FIG. 1 which shows one of each. In a preferred embodiment, all of the elements of the optical cross-connect 10 are formed as a semiconductor package. As shown in FIG. 2, the elements all extend from a substrate 60 and may be formed integrally therewith using etching techniques known in the prior art. Accordingly, the optical cross-connect 10 can be formed as a semiconductor package which can be used as a "building block" in conjunction with other semiconductor devices in forming a system. It is to be understood that the first waveguides 20 and the second waveguides 30 are shown only of limited length to illustrate the workings of the invention. The optical cross-connect 10 can be formed to be different sizes with the waveguides 20, 30 being of different lengths. In practice the waveguides 20, 30 will often be integrally

formed with, or fused to, waveguides which extend to other systems and/or devices. In addition, optical sources L generate lights signals of one or more wavelengths which propagate through the waveguides 20, 30. The optical sources L may be remotely located from the waveguides 20, 30 with the light signals passing through other waveguides and/or optical devices and/or electro-optical devices before entering the waveguides 20, 30. It should be noted that the waveguides 20, 30 are passive devices with light signals being able to propagate in either direction therethrough. Also, optical sources L may be located so as to direct light in either direction and in one or more of the waveguides 20, 30.

The first waveguides 20, second waveguides 30, and the switching element 50 are formed as either photonic wire waveguides or photonic well waveguides, such as those shown and/or described in U.S. Patent No. 5,790,583 and U.S. Patent No. 5,878,583. To illustrate a general configuration of such designs, FIG. 2 depicts representative cross-sections of the first waveguide 20 and the switching element 50, with the second waveguide 30 being similarly formed. As shown representatively, a core 70 is provided surrounded by layers of cladding 80. The core 70 is the active light carrying medium through which a light signal is propagated.

In a preferred arrangement, the straight portions 52 of the oval resonator 50 are aligned generally parallel to the first waveguide 20. As such straight coupling portions are defined for coupling a portion of a light signal between the oval resonator 50 and the first waveguide 20.

With reference again to FIG. 1, in use, a light signal is propagated through at least the first waveguide 20, but a second light signal may also be propagated through the second waveguide 30. Each of the light signals covers a range of wavelengths, with the light signal being parseable into the respective wavelength portions. To parse a particular wavelength signal from the light signal, an electric voltage is applied to the oval resonator 50 from a controllable electrical source V. In the preferred embodiment, the electric voltage tunes the oval resonator 50 to the desired wavelength. With the light signal propagating through the first waveguide 20 as

illustratively represented by the arrows, a portion of the light signal having the particular wavelength will be caused to couple to the oval resonator 50, which in turn will couple the portion of light signal to the second waveguide 30. Using techniques known in the prior art, the oval resonator 50 is formed and positioned to achieve the desired coupling. The coupled portion of light signal will continue to propagate through the second waveguide 30 in the direction represented by the arrows. As is readily appreciated, rapid tuning of the oval resonator 50 allows for very accurate and selective transfer of signals of particular wavelengths. With a second light signal propagating through the second waveguide 30, the coupled portion of light signal will simply become part of the entire signal. As is readily appreciated, the direction of light propagation designated herein is for convenience only in illustrating the workings of the invention, and the signals may propagate in other directions consistent with the disclosure herein.

It should also be noted that the switching element 50 need not be tuned, thus becoming a passive device which does not transfer any portion of the light signal propagating through the first waveguide 20. Accordingly, the entire light signal would then pass straight through the first waveguide 20.

Preferably, at least two of the switching elements 50A, 50B are disposed in proximity to each of the nodes 40, as shown in FIG. 3. The switching elements 50A, 50B are disposed in different regions X, Y which are defined between portions of the first waveguide 20 and the second waveguide 30 that define the associated node 40. In addition, the switching elements 50A, 50B are located on opposite sides of the node 40, as here in a "catty corner" arrangement.

A separate electric voltage is applied to each of the switching elements 50A, 50B. As such, the switching elements 50A, 50B can "add" / "drop" portions of light signals travelling through both the first waveguide 20 and the second waveguide 30. For example, as described above, the switching element 50A can transfer a portion of the light signal propagating in the

first waveguide 20 to the second waveguide 30. In a similar manner, the switching element 50B can transfer a portion of the light signal propagating through the second waveguide 30 to the first waveguide 20. With the combination of the two switching elements 50A, 50B, portions of light signals can be added and dropped between the first and second waveguides 20, 30. Also, either or both of the switching elements 50A, 50B need not be tuned with either or both signals passing straight through the node 40 and propagating through the respective first or second waveguide 20, 30, respectively.

To further illustrate the workings of the subject invention, reference is made to FIG. 4, wherein the quantities M and N both equal 2. Specifically, two first waveguides 20A, 20B are intersected by two second waveguides 30A, 30B, with four nodes 40A-D being defined. In addition, a respective two of the switching elements 50A-H are disposed in proximity to each of the nodes 40A-D. In the same manner as described above, portions of light signals may be added and dropped between the first waveguides 20A, 20B and the second waveguides 30A, 30B. Table 1 sets forth possible workings of the optical cross-connect of FIG. 4, wherein the switching elements 50A-H may or may not be tuned. (For purposes of Table 1, all switching elements 50A-H are tuned to the same wavelength, when tuned.)

Table 1.

SWITCHING ELEMENTS 50A-H (TUNED=Y; NOT TUNED=N)								OUTPUT OF INPUT SIGNAL A	OUTPUT OF INPUT SIGNAL B	OUTPUT OF INPUT SIGNAL C	OUTPUT OF INPUT SIGNAL D
A	B	C	D	E	F	G	H				
Y	Y	Y	Y	N	N	N	N	TB	SA	TA	SB
N	N	N	N	Y	Y	Y	Y	TB	SB	SA	TA
N	N	Y	Y	N	N	Y	Y	TA	SA	SB	TB

As is readily apparent, any quantities M and N of the first and second waveguides 20, 30, respectively, can be used in similar fashion with signals and portions of signals being transferred from waveguide to waveguide to reach a desired destination. Moreover, with the tuning of switching elements, different portions of the light signals may be controllably transferred.

With continued reference to FIG. 4, and by way of non-limiting example, the operation of the inventive optical switch 10 will now be discussed in detail. Four optical sources L1-L4 generate input signals, designated as A, B, C, and D, which are caused to propagate respectively through the waveguides 20A, 20B, 30A, and 30B. The input signals A-D may each be an optical signal comprised of a plurality of wavelengths, or alternatively, comprised of a single wavelength, as a routine matter of design choice. For example, optical source L1 may provide input signal A to waveguide 20A comprised of wavelengths λ_1 - λ_N. If resonator 50A is tuned to wavelength λ_1, that wavelength is coupled from the optical signal propagating through waveguide 20A by resonator 50A and into waveguide 30A, i.e., that wavelength is dropped from the optical signal in waveguide 20A and output from the optical switch 10 via waveguide 30A. The remaining wavelengths in the input signal A continue propagating through waveguide 20A (i.e., the non-coupled wavelengths), pass-through node 40A, and exit the optical switch 10 via waveguide 20A. Optical source L3 may also provide a multi- or single-wavelength optical signal as input signal C to waveguide 30A, which may be selectively coupled between and among waveguides 20A, 20B, and 30B, and which may also pass-through waveguide 30A, depending upon the selective tuning of the various resonators 50A-H provided as part of the optical switch 10. For example, if the input signal C provided by optical source L3 includes wavelength λ_1, that wavelength may be coupled from waveguide 30A to waveguide 20A by resonator 50A, which is tuned to that wavelength. Various other coupling configurations may be provided in accordance with the present invention, depending upon the composition of the optical signals propagating through the various waveguides 20A, 20B, 30A, 30B, and further depending upon the selective tuning of the resonators 50A-H.

As a further embodiment, reference is made to FIG. 5, wherein four of the switching elements 50I-L are located in proximity to the node 40. Advantageously, with four of the switching elements 50I-L light signals may be passed through either of the waveguides 20, 30

and switched in either direction. Stated differently, by having switching elements 50 between each pair of adjoining portions 201-301, 301-202, 202-302, 302-201 of the waveguides 20, 30, signals, or portions thereof, may be switched between the adjoining waveguides 20, 30. In contrast, with reference to FIG. 3 by example, light signals may not be switched about regions A and B. Thus, a signal propagating rightwardly through the waveguide 20 could not be switched upwardly to propagate through the waveguide 30, and vice versa.

In addition to using oval resonators as the switching elements 50, elliptical resonators 500 can be used, such as that shown in FIG. 6, and circular resonators 501 can be used, such as that shown in FIG. 7. With an elliptical resonator 500, it is preferred that the major axis (MA) of the resonator be generally parallel to the first waveguide 20, and the minor axis (NA) be generally parallel to the second waveguide 30. In addition, the switching elements 50 may be MEMS (micro-electromechanical system) switches with mirrors.

Furthermore, the switching element 50 may be a directional coupler where frequency selectivity is not a concern, such as that shown in FIG. 8 and designated with reference numeral 502. Directional couplers are known in the prior art. Copending U.S. Patent Application ________________, to the same inventors and assignee herein, discloses a directional coupler utilizable with the subject invention, and said disclosure is incorporated by reference herein.

The directional coupler 502 includes straight portions 503 and a curved portion 504 which faces the node 40. The straight portions 503 are generally parallel to portions of the first waveguides 20 and the second waveguide 30, respectively. In use, the directional coupler 502 causes coupling of an entire light signal propagating through the first waveguide 20 to the second waveguide 30 in a deactivated state (i.e., no electrical voltage being applied). With an electric voltage being applied, the directional coupler 502 is activated, and the entire light signal passing through the first waveguide 20 will by-pass the directional coupler without there being any coupling of signal to the second waveguide 30. The directional coupler 502 is formed and

positioned to achieve the necessary coupling in a deactivated state (i.e., proper coupling lengths; gap width between directional coupler and waveguides, etc., are provided).

In another aspect of the invention, referring to FIGS. 9A and 9B, portions of the waveguides 20, 30 at, and in proximity to, the nodes 40 are enlarged to increase the area of the nodes 40. Thus, the waveguides 20, 30 are each formed with a width w at, and in proximity to, the nodes 40 which is greater than the width h of the remaining portions of the waveguides 20, 30. The waveguides 20, 30 need not have the same widths w or the same widths h. Additionally, the enlarged portions of the waveguides 20, 30 may be connected with remaining portions of the waveguides 20, 30 either with straight tapered portions 90 (FIG. 9A) or arcuate portions 100 (FIG. 9B). With an enlarged area, less diffraction occurs at the nodes 40 and, thus, signal cross-talk is reduced of signals passing through the nodes 40. Additionally, signal loss is reduced.

The first and second waveguides 20, 30 can be arranged in a perpendicular matrix arrangement, as shown in FIG. 4. Alternatively, with reference to FIG. 10, the first and second waveguides 20, 30 can be arranged with portions thereof being generally parallel. As shown in FIG. 10, a straight portion 110 of the first waveguide 20 is generally parallel to a straight portion 120 of the second waveguide 30. In addition, returning to the preferred embodiment, the straight portions 52 of the oval resonator 50 are also arranged generally parallel to the straight portions 110, 120. With this arrangement, the oval resonator 50 has straight portions 52 coupling with the straight portions 110, 120, thereby increasing the efficacy of signal transference. Additionally, the oval resonator 50 can be used to transfer signals between both the first waveguide 20 and the second waveguide 30.

Thus, while there have been shown and described and pointed out fundamental novel features of the invention as applied to preferred embodiments thereof, it will be understood that various omissions and substitutions and changes in the form and details of the disclosed

invention may be made by those skilled in the art without departing from the spirit of the invention. It is the intention, therefore, to be limited only as indicated by the scope of the claims appended hereto.

CLAIMS

What is claimed is:

1. An optical cross-connect comprising:

a first waveguide;

a second waveguide intersecting said first waveguide with a node being defined at the intersection of said waveguides; and,

a first switching element disposed in proximity to said node to selectively transfer at least a portion of a light signal propagating through said first waveguide to said second waveguide.

2. An optical cross-connect as in claim 1, wherein said first switching element is a resonator.

3. An optical cross-connect as in claim 2, wherein said resonator is oval-shaped.

4. An optical cross-connect as in claim 2, wherein said resonator is electrically tuned to control the selective transfer of at least a portion of the light signal.

5. An optical cross-connect as in claim 1, wherein said first switching element is a directional coupler.

6. An optical cross-connect as in claim 1 further comprising a third waveguide and a fourth waveguide, wherein said second waveguide intersects said third waveguide, said fourth waveguide intersects both said first and third waveguides, and wherein a node is defined at each intersection of said waveguides.

7. An optical cross-connect as in claim 1, wherein said first waveguide and said second waveguide each include a first portion in proximity to said node and a second portion farther from said node than said first portion; said first portion and said second portion

each having a width, the width of said second portion being greater than the width of said first portion.

8. An optical cross-connect as in claim 7, wherein said first waveguide and said second waveguide each have a third portion connecting the respective first portion with said second portion of the waveguide; said third portion being tapered.

9. An optical cross-connect as in claim 7, wherein said first waveguide and said second waveguide, each have a third portion connecting the respective first portion with said second portion of the waveguide; said third portion being arcuate.

10. An optical cross-connect as in claim 1 further comprising at least a second switching element disposed in proximity to said node to selectively transfer at least a portion of a light signal propagating through said second waveguide to said first waveguide, and wherein said first switching element is located in a first region defined between portions of said first waveguide and said second waveguide, said second switching element is located in a second region defined between portions of said first waveguide and said second waveguide, at least one of said first waveguide and said second waveguide being disposed between said first switching element and said second switching element.

11. An optical cross-connect as in claim 10 further comprising a switching element located between each pair of adjoining portions of said waveguides.

12. An optical cross-connect as in claim 1, wherein said first waveguide, said second waveguide, and said first switching element are integrally formed as a semiconductor package.

13. An optical cross-connect as in claim 1, wherein a portion of said first waveguide is disposed generally parallel to a portion of said second waveguide.

14. An optical cross-connect as in claim 12, wherein said switching element is disposed between the parallel portions of said first waveguide and said second waveguide.

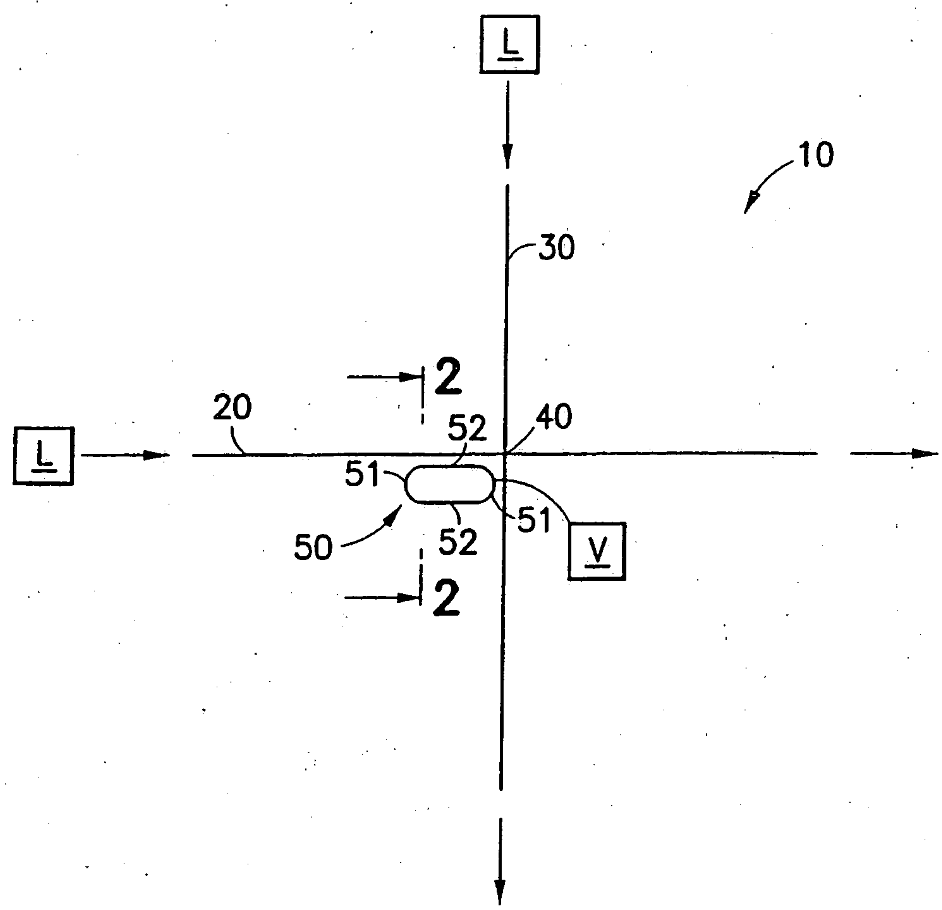
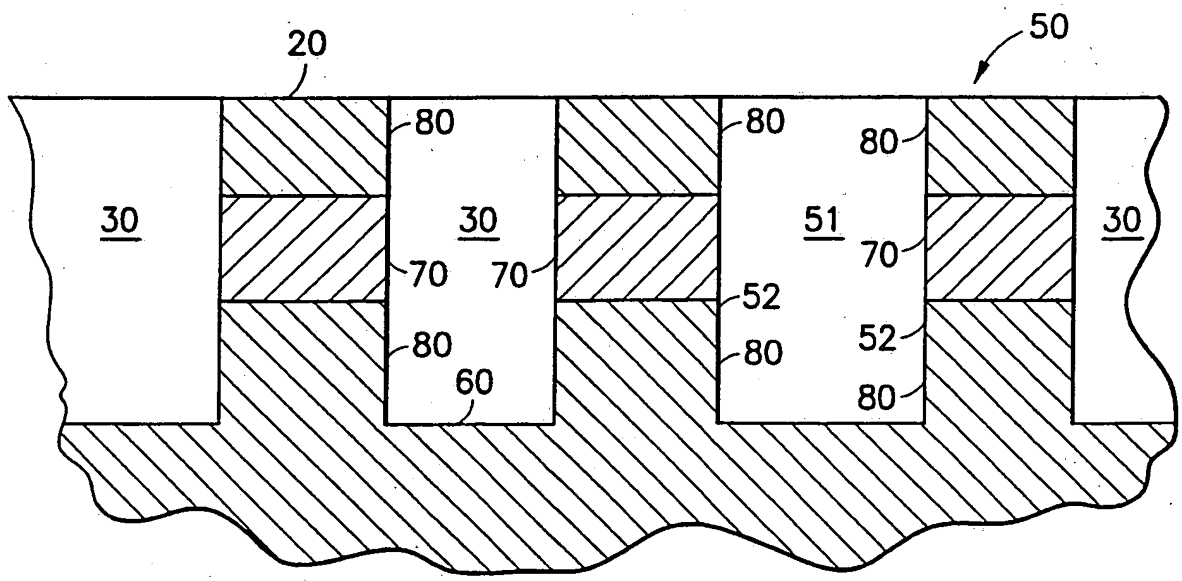

L
10
30
2
20
52
40
L
51
51
V
50
52
2

FIG.1


20
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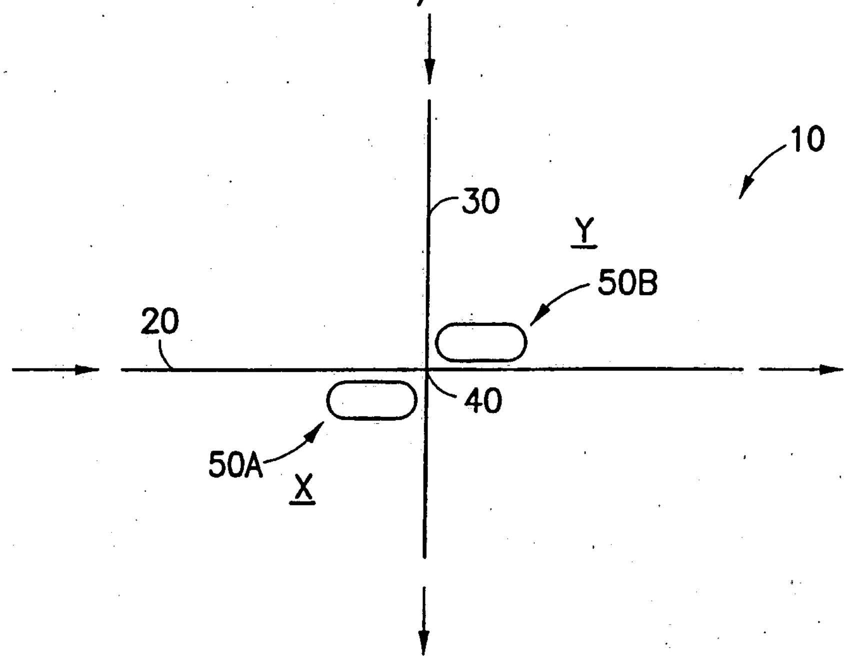
80

FIG.2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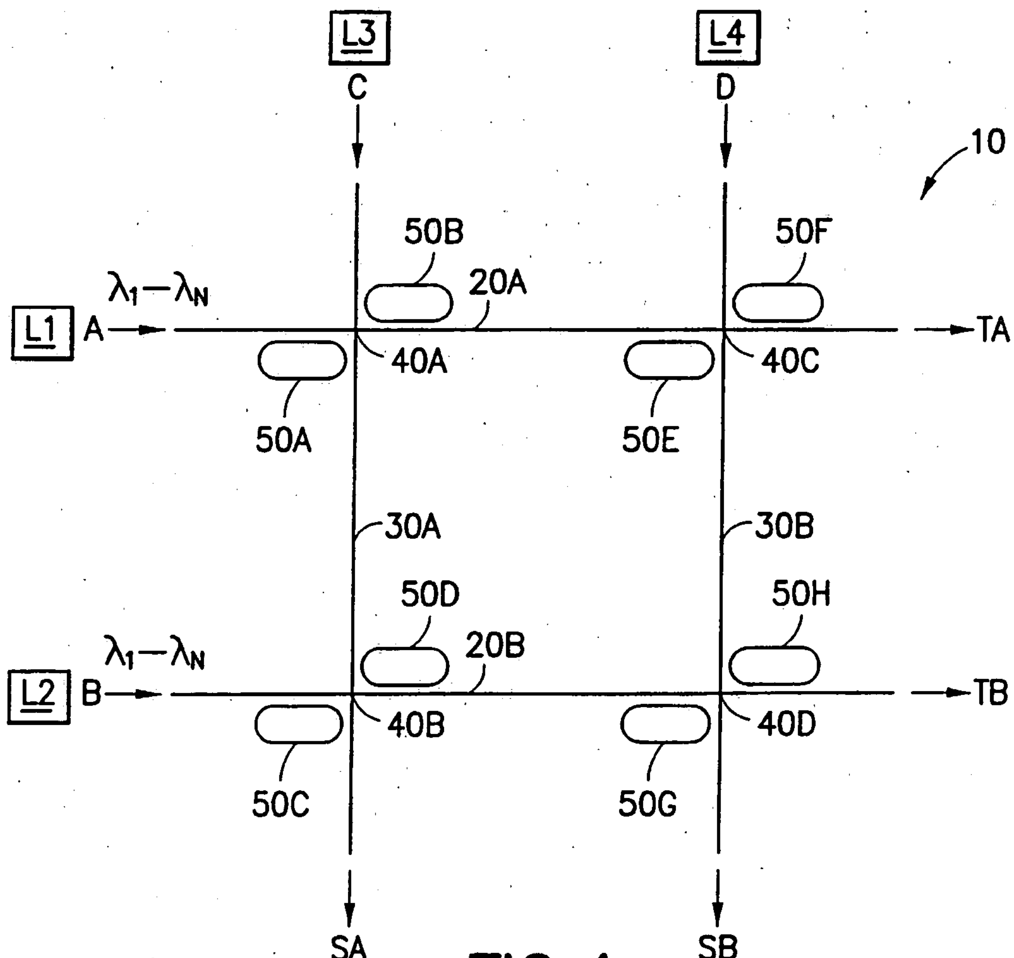
30
Y
50B
20
40
50A
X

FIG.3


L3
C
L4
D
10
50B
50F
20A
$\lambda_1-\lambda_N$
L1
A
TA
40A
40C
50A
50E
30A
30B
50D
50H
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$\lambda_1-\lambda_N$
L2
B
TB
40B
40D
50C
50G
SA
SB

FIG.4

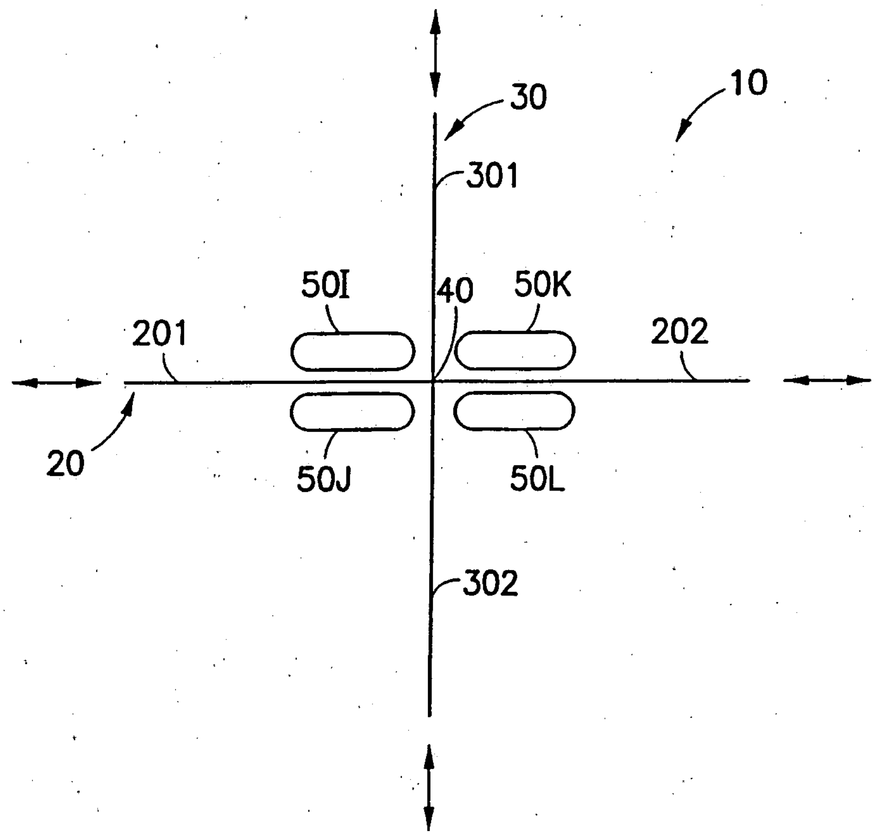

FIG.5

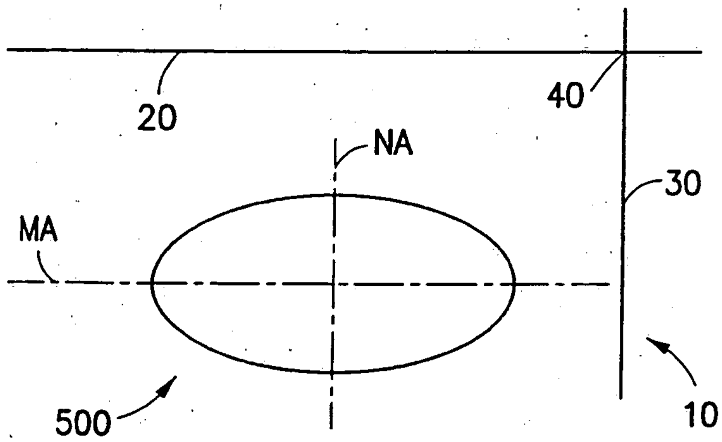

FIG.6

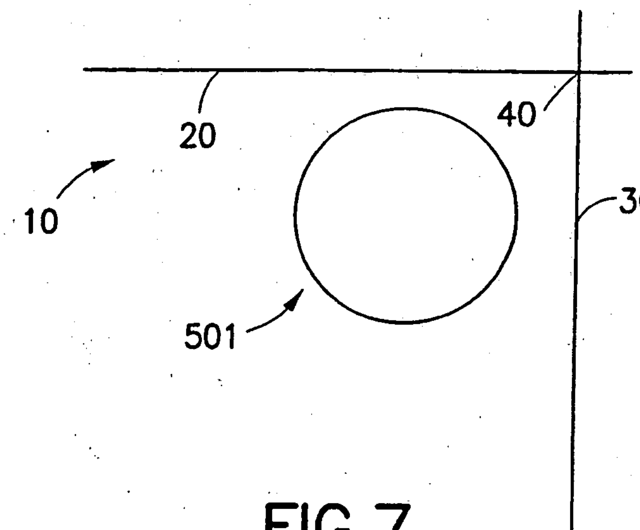

FIG.7

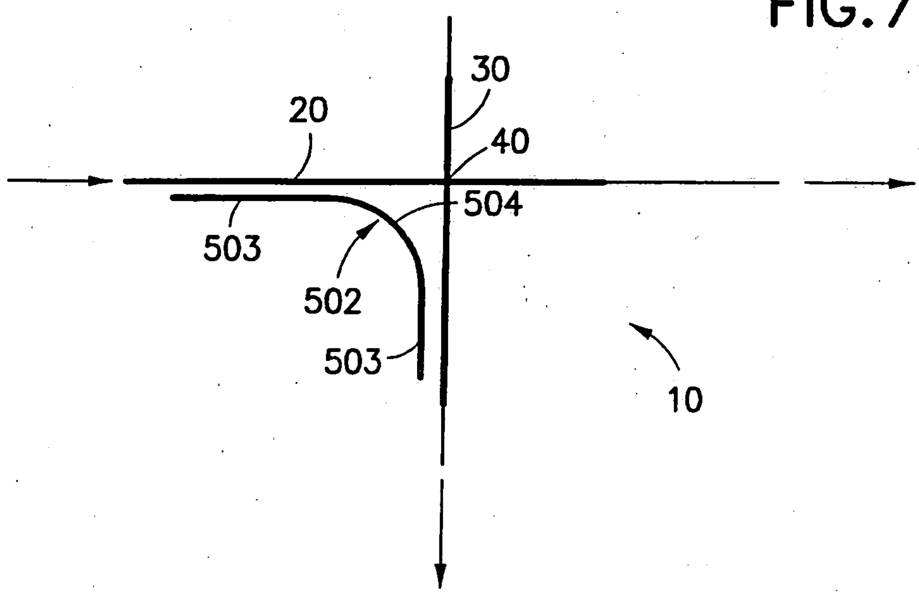

FIG.8

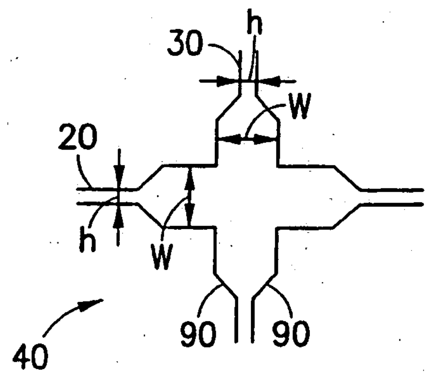

FIG.9A

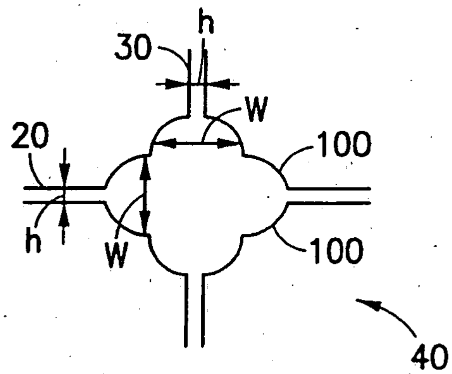

FIG.9B

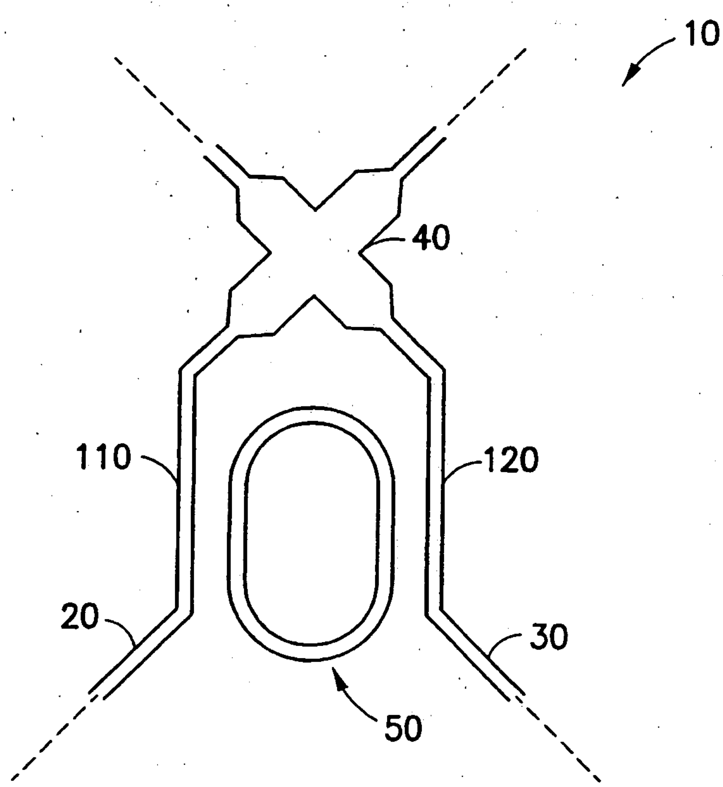

FIG.10

INTERNATIONAL SEARCH REPORT

Intern: al Application No
PCT/US 00/13728

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B6/12 G02F1/29

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 210 991 A (OKI ELECTRIC IND CO LTD) 21 June 1989 (1989-06-21) page 4, line 22 -page 7, line 21; figures 3-5 ---	1,5
A	SOREF R A ET AL: "PROPOSED N-WAVELENGTH M-FIBER WDM CROSSCONNECT SWITCH USING ACTIVE MICRORING RESONATORS" IEEE PHOTONICS TECHNOLOGY LETTERS,US,IEEE INC. NEW YORK, vol. 10, no. 8, 1 August 1998 (1998-08-01), pages 1121-1123, XP000769876 ISSN: 1041-1135 the whole document ---	1,2,4

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
17 October 2000	03/11/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Diot, P

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